THE RUNWAY LENGTH FOR THE TAKE-OFF OF THE GREATEST AIRPLANE OF THE WORLD: THE AIRBUS 380

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INTRODUCTION

In this research is analyzed the take-off theory for the greatest airplane of the world: the Airbus 380-800, nicknamed "Super Jumbo". Many international runways do not have the sufficient length to the critical take-off of this new airplane. The acting forces in the take-off are estimated; through a theoretical procedure the spaces, the times and the accelerations are determined in every phase of the take-off. Their numerical values are compared with those obtained applying the same procedure to other "Giants" of the air which: the Boeing 747, nicknamed "Jumbo", and the Boeing 777. Some parameters used in the calculation are: the aircraft dimensions, the gross weight acts through the gravity center of the aircraft, the take-off thrust of the motors, the speeds, the aerodynamic lift and drag coefficients, the airfield altitude, varying climatological conditions (the standard day temperature, the wind), the air density, the friction coefficient. Finally the theoretical values are confronted with those declared from the airplane manufacturers.

Super Jumbo

The procedure of the Airbus 380 (Super Jumbo) critical takeoff is shown through the formulation of a theory that with only one mathematical expression defines times, accelerations, spaces of a whichever aircraft (jet) in normal, critical and interrupted take-off. Particular attention has been turned to the A380 that, in a short time, will be the greatest airplane of the world; its dimensions, in fact, are such as:

- it cannot be contained in a field of soccer (Fig.1),
- it is greater then modern B747 Jumbo (Fig.2),

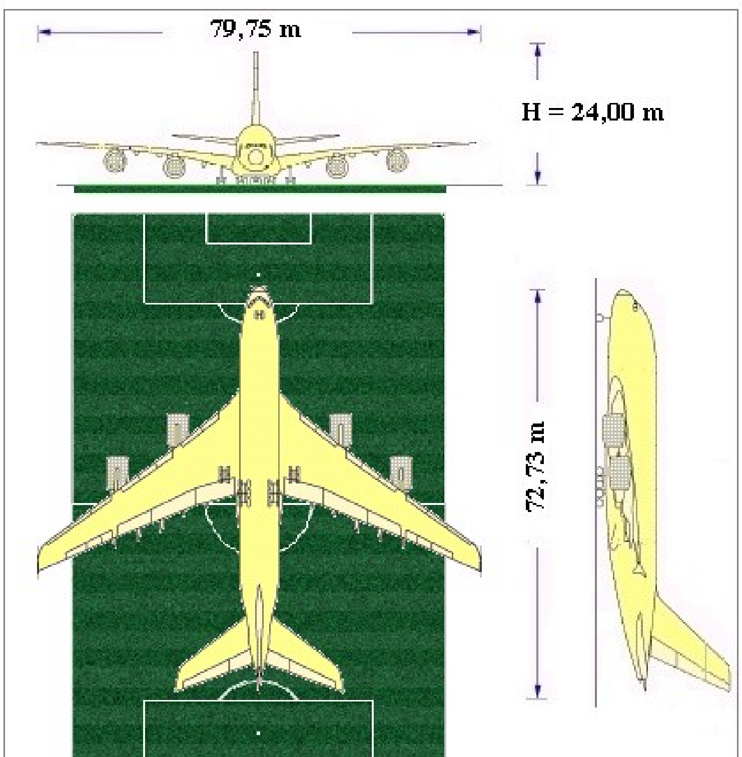

Figure 1

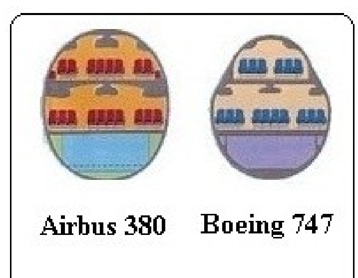

Figure 2

- many characteristics exceed those of Boeing777 and Boeing747 (Fig.3).

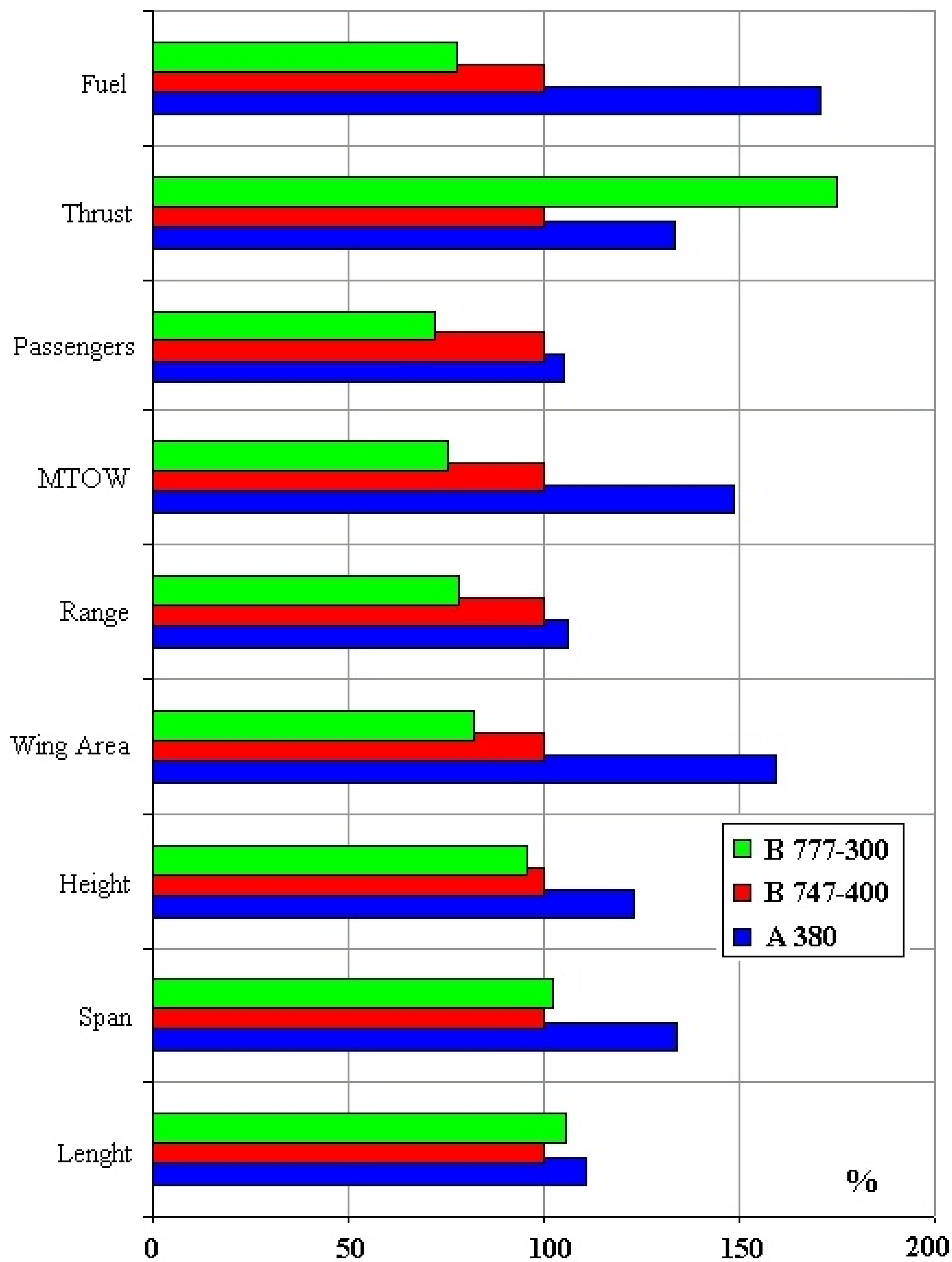

Figure 3

The Fig.4 shows the outlines of the three possible maneuvers of jet takeoff; every maneuver has been subdivided in phases. They are characterized from the spaces S, from the values of speeds V and from the behavior that the pilot has when there is a damage to the propulsive system.

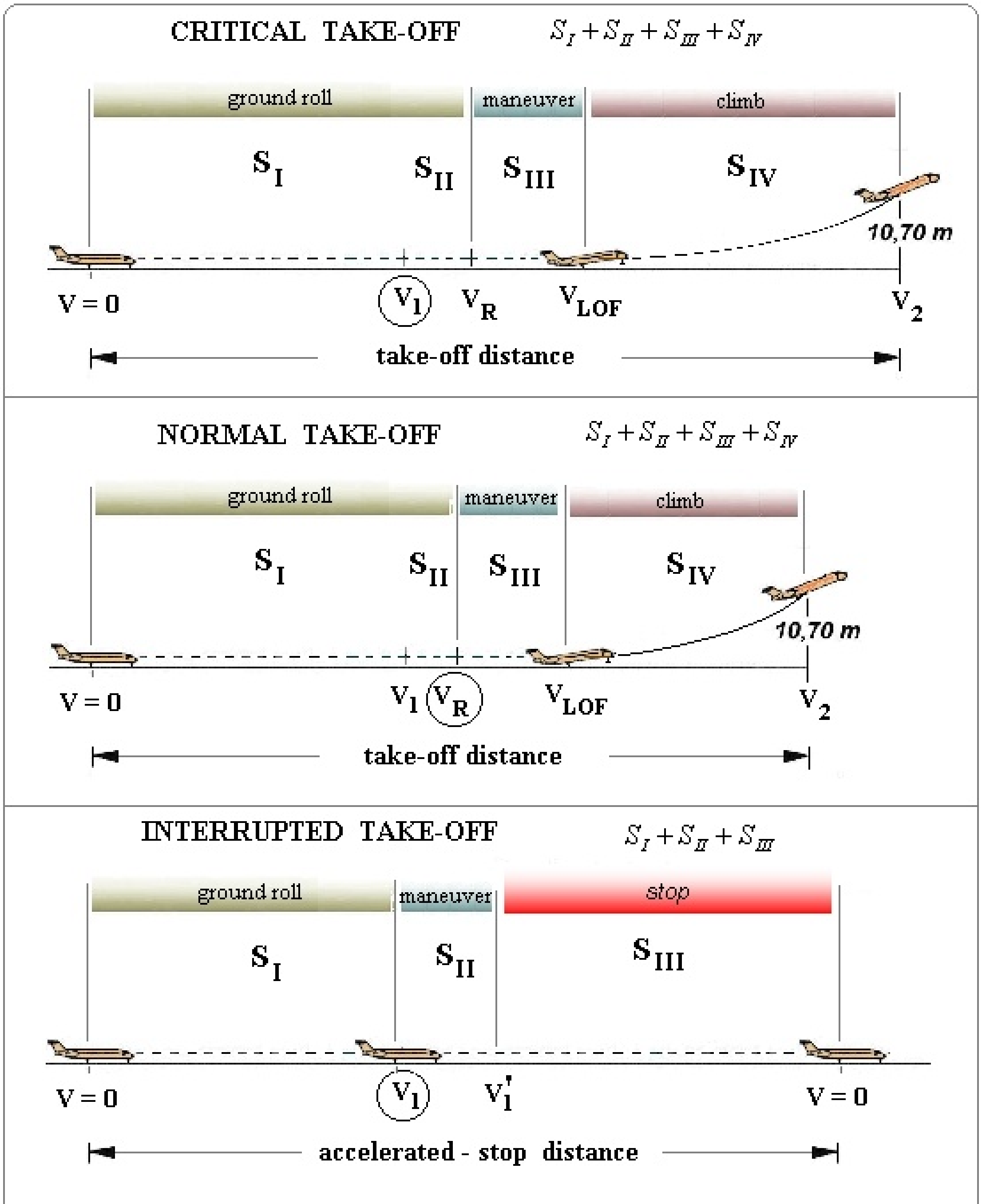

Figure 4

If an engine fails, the take-off continues or is interrupted in relation to the runway point where the damage has happened. Therefore exists *a critical distance* from the beginning runway, where the aircraft begins braking and stops before the end of runway, or the aircraft continues the take-off and overcomes the true or virtual obstacle foreseen by the normative. The rule indicates that the take-off of the multi-engine aircrafts must happen also with a engine failure from the beginning of the maneuver; *the operating critical engine* is that engine whose damage involves the more critical consequences for the safety of the flight. In particular, the critical state of a unit engine depends by its position in the architecture of the aircraft; for example, in the case of Airbus 380, one whichever of the two more external engines can be the *critic one,* because the damage involves the greatest yawing brace. In this case, during the take-off, two extreme conditions of damage can be present to the pilot:

- engine in damage, already to the beginning of the take-off phase;
- engine in damage in any point of the runway.

In the first condition, rare for a jet, the airplane begins the take-off with a not working motor; in these conditions (*reduced power*) the space, the time of takeoff and the acceleration, can be determined with the general procedure that will be explained later. Obviously the takeoff space at *reduced power* (leaving all the other conditions unchanged) is greater than *normal,* at full power. In the second condition, equally rare, but more frequent than the first one, the damage of the engine happens in any point of the take-off; in this hypothesis the pilot can hold two different behaviors:

- if $V(t)>V_1$: he continues the take-off and overcomes the obstacle imposed by the rule
- if $V(t)<V_1$: he aborts the take-off and comes to a stop.

being: - $V(t)$ the aircraft speed when the damage is introduced,
- V_1 the "*Take Off Decision Speed*" or "*critical engine failure speed*".

The V_1 speed, therefore, defines the point on the runway in which the distance required by the aircraft to stop coincides with the distance necessary to reach the V_2 speed: *take off speed*; in this case the runway is called *balanced*.
Only the first one of two behaviors of the pilot has been considered in the formulation of this procedure. The Fig.4 outline distinguishes the maneuver of critical takeoff to V_1 in four phases: the first two re-enter in the phase of taxiing (the motion of the aircraft is similar to that of a road vehicle); the third is associated to the phase of maneuver and, finally, the fourth is associated to the phase of climb. With this formulation also the maneuver of normal take-off is formally represented by four addends: the first is equal to that of the critical take-off, while the last three have inferior values. Instead, the maneuver of take-off interrupted to V_1, introduces only three phases: the first is equal to that of the critical take-off, the second is characterized from the technical time necessary to the pilot to operate the reverse and the mobile jet parts, finally, the third is a classic phase of braking at the end of which the aircraft stops on the runway.

Finally, to obtain the maximum take-off space, the aircraft will be supposed firm on the runway's threshold when it receives the OK from the flight controllers. This formulation considers the maneuvres of the normal and interrupted take-off as two particular cases of that (plus general) of critical take-off. The Tab.1 recapitulates some formulas used in this research.
The speeds and the parameters to which we will refer in the carrying on, are:

symbol	*meaning*
V(t)	the speed of the airplane in the generic moment t
V_1	Take Off Decision Speed
V_R	Rotation Speed
V_{lof}	Lift Off unstick Speed
V_2	Minimum Take Off Safety Speed
β	angle that the runway axis forms with the horizontal plan
ρ	density of the air at altitude zero on the mean sea level
$C_{R,i}$	drag coefficient in the generic phase i (i = I, II, III, IV)
$C_{P,i}$	lift coefficientet in the generic phase i (i = I, II, III, IV)
S	the airplane surfaces (wing span)
f	resistance specific (average) to the rolling without braking effect
g	gravitational acceleration
15°C	standard temperature air
ν	angle of inclinationof the take-off thrust reported to the aircraft's longitudinal axle
$C_{R,i}$, $C_{P,i}$	coefficients defined from the polar correspondent to the incidence angles

TABLE 1

phase	I	II	III	IV
				
V	$0 \le V(t) \le V_1$	$V_1 < V(t) \le V_R$	$V_R < V(t) \le V_{lof}$	$V_{lof} < V(t) \le V_2$
$\frac{dV}{dt}$	$A_I - B_I V - C_I V^2$	$A_{II} - B_{II} V - C_{II} V^2$	$A_{III} - B_{III} V - C_{III} V^2$	$A_{IV} - C_{IV} V^2$
A_i	$g\left(\frac{T_o}{Q} - f\cos\beta - \sin\beta\right)$	$g\left(\frac{\eta T_o}{Q} - f\cos\beta - \sin\beta\right)$	$g\left(\frac{\eta T_o}{Q}(\cos\theta + f\sin\theta) - f\cos\beta - \sin\beta\right)$	$\frac{V_2^2 - KV_{lof}^2}{V_2^2 - V_{lof}^2} a_C$
B_i	$g\frac{T_o}{Q}\chi$	$g\eta\frac{T_o}{Q}\chi$	$g\eta\frac{T_o}{Q}\chi(\cos\theta + f\sin\theta)$	---
C_i	$\frac{g\rho S}{2Q}(C_{R,I} - fC_{P,I})$	$\frac{g\rho S}{2Q}(C_{R,II} - fC_{P,II})$	$\frac{g\rho S}{2Q}(C_{R,III} - fC_{P,III})$	$\frac{1-K}{V_2^2 - V_{lof}^2} a_C$
Space	$S_i = -\frac{1}{C_i}\left[m_i \ln\frac{\lvert V_{fin} + \delta_1^i\rvert}{\lvert V_{ini} + \delta_1^i\rvert} + n_i \ln\frac{\lvert V_{fin} - \delta_2^i\rvert}{\lvert V_{ini} - \delta_2^i\rvert}\right]$			
Time	$t_i = -\frac{1}{C_i}\left[r_i \ln\frac{\lvert V_{fin} + \delta_1^i\rvert}{\lvert V_{ini} + \delta_1^i\rvert} + s_i \ln\frac{\lvert V_{fin} - \delta_2^i\rvert}{\lvert V_{ini} - \delta_2^i\rvert}\right]$			
m_i	$0 < m_i = \frac{-\delta_1^i}{-\delta_1^i + \delta_2^i} < 1$			
n_i	$0 < n_i = \frac{\delta_2^i}{-\delta_1^i + \delta_2^i} < 1$			
r_i	$r_i = \frac{-1}{-\delta_1^i + \delta_2^i} < 0$			
s_i	$s_i = \frac{1}{-\delta_1^i + \delta_2^i} > 0$			

The parameters used in the calculations are (Fig.5):

- **Q** the aircraft weight (MTOW), constant along the takeoff maneuvers; it is given from the sum of the contributions:

$$Q = Q_{structure} + Q_{fuel} + Q_{reserve} + Q_{payload} \qquad (1)$$

- **P_1, P_2** the aerodynamic lift forces, generated from all the aircraft wings; they act perpendicular to the flight path and they are variables with time:

$$P(t) = P_1 + P_2 = \frac{1}{2}\rho\, C_{P,I}\, S\, V(t)^2 \qquad (2)$$

- **N_1, N_2, N_3** the interaction vertical forces between every body gear, every nose gear, every wing gear, and the runway pavement; they are variables with time.

- **f N_1, fN_2, fN_3** interaction tangential forces between the wheels and pavement; they are variables during the take-off, they depend from: the pavement type and the quality tires.

- **T** the thrust of the turbines, it's initially produced by four A380engines; often, it is assumed parallel to the longitudinal axis of aircraft ($\nu \cong 0$), and its intensity varies with the speed V(t) according to the formula:

$$T(t) = T_o\left[1 - \chi\, V(t)\right] \qquad (3)$$

  T_o is the thrust at fixed point and χ a reductive coefficient tied to the typology engines.

- **R_1, R_2, R_3,** the distinguished aerodynamic resistances in the three contributions: the central body centers, the tail and the wings of the airplane. Their sum furnishes the total resistance R(t) to the ground, varying during the take-off, it assumes the form:

$$R(t) = \frac{1}{2}\rho C_{R,I} S V(t)^2 + Q\sin(\beta) + f\left[Q\cos(\beta) - \frac{1}{2}\rho C_{P,I} S V(t)^2\right] \qquad (4)$$

- i, the pointer of the analyzed phase (i = I, II, III, IV);

- δ^i_1 e δ^i_2, the two real roots of the trinomial acceleration;

- m_i, n_i, r_i, s_i, the coefficients of the takeoff space and the takeoff time;

- V_{ini} e V_{fin} the aircraft speeds at the beginning and the end of every phase.

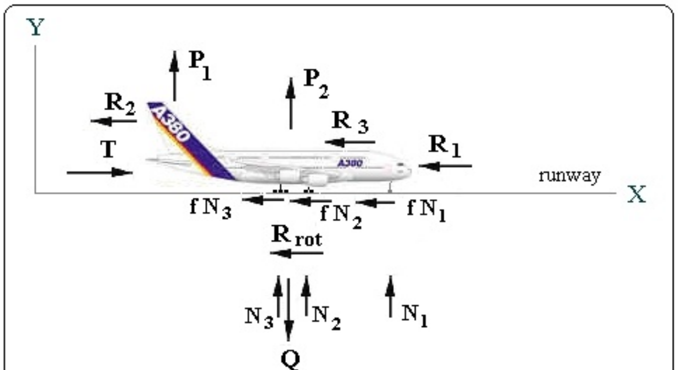

Figure 5

THE RESULTS

From the application of the procedure, the following diagrams have been produced from which have derived these considerations (Analogous considerations can be made for the times of normal and critical takeoff).The Figure 6 is prepared for one particular A380 version, MTOW≅600 ton:

- in the standard conditions the critical take-off space exceeds approximately of 32% the normal take-off;
- the II and III phases have a secondary role because they amount, respectively, to 9% and to 4% of the critical take-off;
- the phase I, is certainly the most important: it influences for 55% the critical takeoff and for 73% the normal take-off.

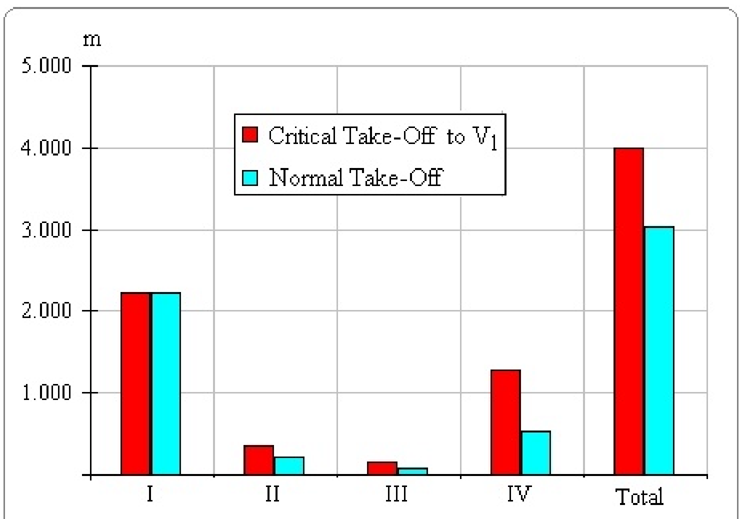

Figure 6

The Figure 7, instead, confronts the critical take-off spaces of the Airbus 380 with those of others two giants of the air: the B747 in two versions 200 and 400. The results show sensitive increases of the runway length required by the A380 towards the B747: around 31% ($B747_{200}$) and 15% ($B747_{400}$). These deviations will be more marked when the standard conditions will be more distant. Analogous considerations can be done analyzing the take-off times.

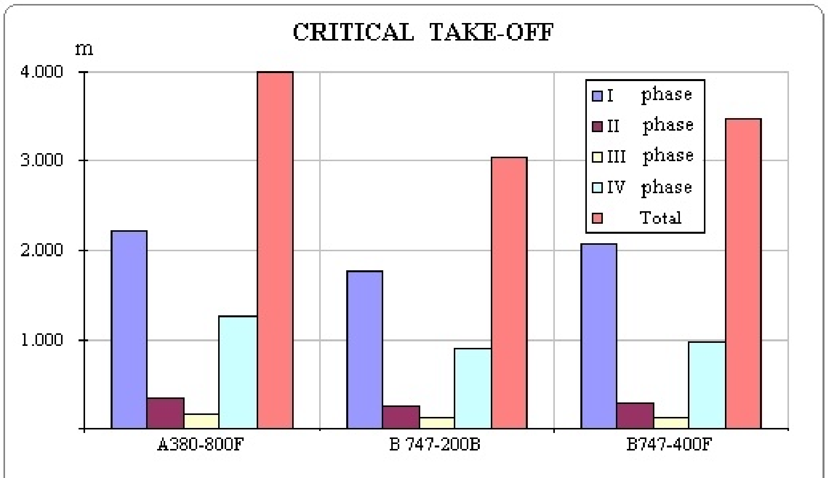

Figure 7

In the hypothesis of normal take-off and equal thrust push motors, the Figure 8 shows, varying the A380 mass, the spaces required from the European aircraft to 1 ton take-off. We can observe the greater slope of the curve related to the Phase I, in comparison to those of the remaining phases.

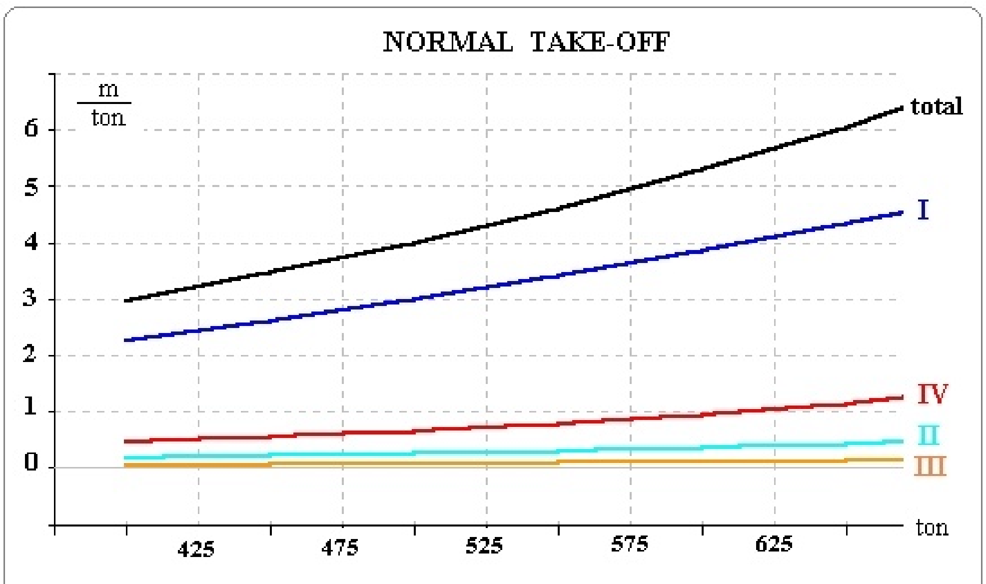

Figure 8

The Figure 9 is analogous to Figure 8; it determines the critical take-off space for every unit of transported mass. In this case, the phase IV assumes a very important role when the mass of the A380 is ≥ 600 tons. The hypothesis, equal thrust varying the aircraft mass, doesn't appear more formally corrected. Therefore, for elevated load configurations, the generated power by engines must be increased.

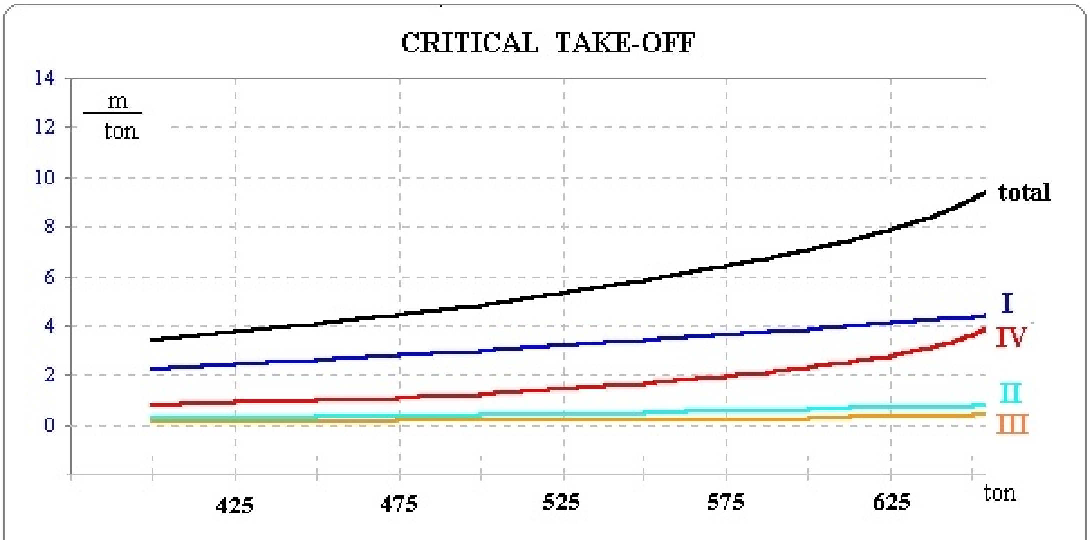

Figure 9

Finally, the Figure 10 confronts the spaces of normal take-off, critical take-off to V_1 and interrupted take-off to V_1; when the airplan mass is >500 tons, the space required by the critical takeoff is always greater of that interrupted. Instead, when the A380 mass reachs the 650 tons approximately, the normal take-off requires a length of the runway superior to that of the interrupted take-off. Any is the value of the airplane mass, the normal take-off needs of a runway length inferior to that of critical take-off always.

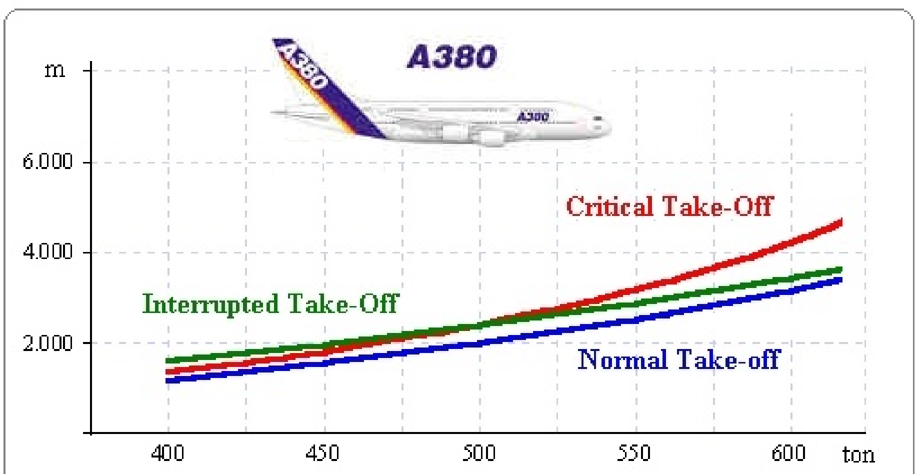

Figure 10

CONCLUSIONS

We have demonstrated that in standard conditions the runway length, required from the new A380 aircraft, appears remarkable, above all when the critical take-off is to the maximum weight. The runway length is always superior to that required, in the same conditions, from the B747. The necessary spaces for the take-off will be increased ulteriorly when the temperature of reference and the airport altitude are various from those standards. Since the A380 aerodynamic coefficients are not known, they has been determined for comparison (regression analysis) with other aircrafts. Therefore the validity of the numerical results obtained in this research are subordinated to the real values that the aircraft will achieve in the homologation tests.

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The Authors declare to have contributed fairly to the preparation of the present research.